

Commonality between Reduced Gravity and Microgravity Habitats for Long Duration Missions

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Abstract - *Many conceptual studies for long duration missions beyond Earth orbit have assumed unique habitat designs for each destination and for transit habitation. This may not be the most effective approach. A variable gravity habitat, one designed for use in microgravity, lunar, Martian, and terrestrial environments may provide savings that offset the loss of environment-specific optimization. However, a brief analysis of selected flown spacecraft and Constellation-era conceptual habitat designs suggests that one cannot simply lift a habitat from one environment and place it in another that it was not designed for without incurring significant human performance compromises. By comparison, a conceptual habitat based on the Skylab II framework but designed specifically to accommodate variable gravity environments can be shown to yield significant advantages while incurring only minimal human performance compromises.*

Keywords: Human space exploration, Lunar habitat, Mars habitat, Deep Space Habitat, long duration.

1 Introduction

Traditionally, a spacecraft is designed for a specific mission application. The Apollo Lunar Lander was designed for lunar surface ascent and descent with very limited, short duration habitation. The Salyut and Mir space stations were designed exclusively for use in low Earth orbit (LEO). Immediately following the cancellation of the Constellation program there was significant angst in NASA spacecraft design communities because there was no clear destination around which to base future vehicle designs.

It is not intuitive to design spacecraft without a specific destination. Recent studies have attempted to apply existing spacecraft hardware to destinations for which they were designed with disappointing results. Cislunar studies in particular considered the use of the ISS Node 1 structural test article (currently located at Kennedy Space Center) but determined that the module's LEO design was not well-suited for the Cislunar space environment.

Typically a spacecraft is designed based on a very specific set of requirements and operations concepts. When such a spacecraft is applied to a destination that would have different requirements and operations concepts it is likely that would have led to a different design.

Microgravity transit habitats are required for missions involving long duration voyages to Mars or Near Earth Asteroids. Microgravity stations are needed for missions in Cislunar/Translunar space, at Near Earth Asteroids, or in the vicinity of Martian moons. Planetary habitats are required for missions on the lunar or Martian surfaces.

A multi-destination exploration architecture involving all of the above missions could theoretically require seven different habitats. It is entirely inconceivable that the NASA budget could allow for seven different habitat project offices to develop unique habitats for each mission environment. Even with international partners such a number is sufficiently improbable to be considered a mission non-starter. Consequently the choice is development of multi-destination habitats or reducing human spaceflight to a single destination per generation.

2 Critique of Skylab in a Planetary Environment

To date, only two US long duration spacecraft have been flown, Skylab and the International Space Station. Using Skylab as an example, how would it fare if removed from its designed microgravity environment and placed in a lunar or Martian surface environment?

2.1 Skylab

The Skylab space station, shown in figure 1, was America's first space station. Built from leftover Apollo hardware, Skylab included three main pressurized elements: the Orbital Workshop, Airlock Module, and Multiple Docking Adapter and had a volume of 360 m³. [4] The spacecraft was used to conduct microgravity science missions in Low Earth Orbit of increasing duration.

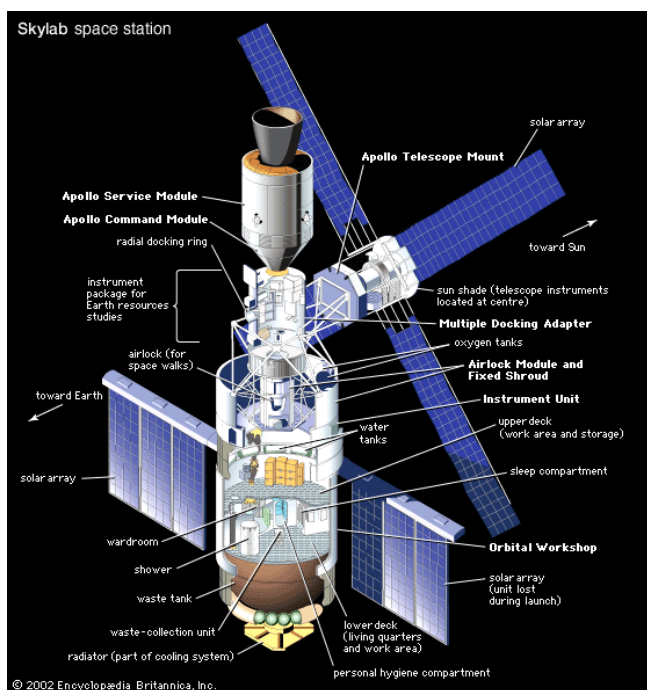


Figure 1. Skylab Space Station [4]

It is fairly obvious at a first glance that Skylab as configured is not suitable for use in a planetary environment, but several key issues will be discussed nonetheless.

2.1.1 Orbital Workshop

The primary living and working volume in Skylab is the Orbital Workshop (OWS). This structure, shown in figure 2, is a converted S-IVB stage, the third stage of the Saturn V rocket. This stage measures approximately 22 feet in diameter and 44 feet in height. [6]

The liquid hydrogen tank was built into the pressurized element and the liquid oxygen tank was used as an uninhabited waste stowage volume. The hydrogen tank was divided into two vertically oriented decks. The lower habitation deck contained private crew quarters, exercise, hygiene, dining facilities, and access to the waste stowage volume. The upper habitation deck contained stowage, science equipment, a large interior open volume used for shirt sleeve testing of the Manned Maneuvering Unit (MMU) prototype, and access to the Airlock Module.

The vertical orientation of the OWS means that if applied to a planetary mission the module would be oriented vertically, with the waste stowage volume closest to the surface and the other decks rising above it. A few examples of problems resulting from such a configuration will be briefly described.

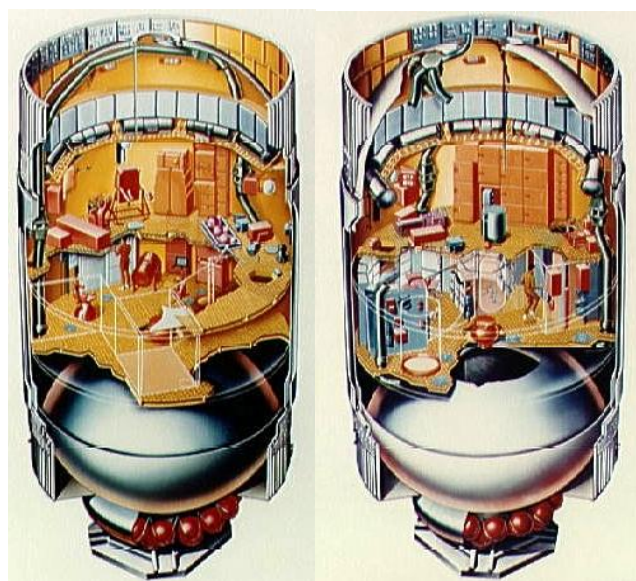


Figure 2. Skylab Orbital Workshop [4]

As configured, the module is inaccessible in a planetary environment. The only access to the module interior is the hatch at the top of the module that connects it to the Airlock Module. This is at the top and in the center of the large open volume on the upper deck. The hatch is too high to be reached without ladder or stairs, not presently in the vehicle.

The wardroom table is located in a somewhat confined area on the lower deck. Astronauts complained that the SPT crew member had to crawl over the others to maneuver between his eating station and the food preparation area. [5] While annoying but manageable in a zero gravity environment, it would be unacceptable to have to crawl over the table or other crew members in a planetary environment.

The sleep stations in Skylab are private crew quarters with the sleep berths mounted vertically on the walls. Once applied to a planetary environment it is impossible for crew to sleep in this position. There is insufficient square footage in each crew quarters to reorient the sleep bunks to the horizontal position.

2.1.2 Airlock Module

The Airlock Module (AM) is located above the OWS, as shown in figure 1. In addition to the previously mentioned problem with access from the OWS in a planetary environment, a crew member would egress a planetary Skylab more than 44 feet above the surface. There is presently no other location on Skylab where the AM can be attached without significant redesign.

2.1.3 Multiple Docking Adapter

The Multiple Docking Adapter (MDA) is located above the AM as shown in figure 3. Two ports are available for docking Apollo Command Modules and the Apollo Telescope Mount has an unpressurized attachment. Applying this architecture to a surface outpost is completely unworkable. The side Apollo Telescope Mount and alternate docking ports would not be able to sustain the loads with Skylab landed vertically on the surface. Further, the primary Apollo docking port is pointed vertically to space, where it would be utterly impractical to dock any visiting vehicle.

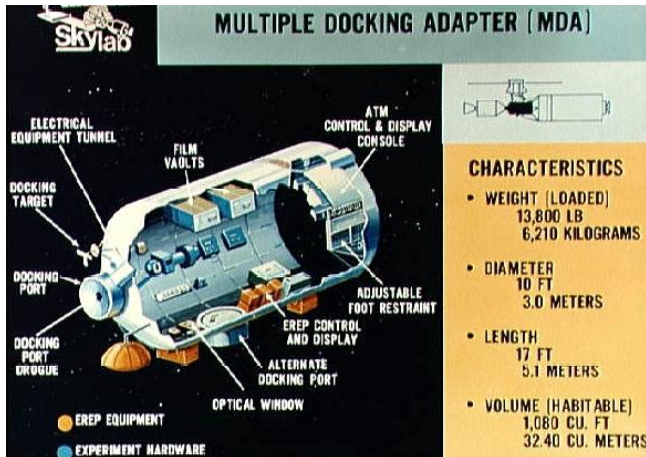


Figure 3. Skylab Multiple Docking Adapter [4]

The primary purpose of this discussion is to point out the obvious – that a habitat designed specifically for microgravity cannot be simply repurposed to a planetary environment. Thus, a multi-destination habitat cannot begin as a microgravity habitat.

3 Critique of Select Constellation Lunar Surface Habitats in a Microgravity Environment

3.1 Lunar Surface Scenario 12.1

During the Constellation program, the Lunar Surface Systems Project developed numerous design concepts for lunar surface outposts, organized under numbered Lunar Surface Scenarios. Lunar Surface Scenario 12.1 (LSS 12.1) was a 4-crew outpost with a volume of approximately 225 m³ [3] intended to sustain a crew of four for a 180-day surface mission.

The LSS 12.1 habitat was composed of eight docked modules. Four modules were identical Lunar Electric Rovers (LERs). The LERs are dual-purposed, used attached to the outpost as single person crew quarters and used detached from the outpost as two-person scout vehicles for missions up to 14 days in duration. The three

cylindrical habitats shown in figure 4 share a similar structure with different internal outfitting and docking ports.

The leftmost habitat – the Pressurized Excursion Module (PEM) is a separable module that can be carried by an ATHLETE (all-terrain-hex-legged-extra-terrestrial-explorer) for one-month excursions from the outpost. It has three docking ports to dock to one LER, an inflatable airlock module, and the rest of the outpost. The PEM contains a suit maintenance workstation, general maintenance workstation, geology workstation, and medical workstation. [9]

Adjacent to the PEM is the Pressurized Core Module (PCM). The PCM contains the bulk of the outpost subsystems equipment, a biology workstation, exercise equipment, galley and wardroom, hygiene facilities, and a mission ops control station. The PCM contains four docking ports. [9]

The Pressurized Logistics Module (PLM) contains only a single docking port, used to dock with the PCM. It is exclusively used for stowage and trash. Unlike the PEM and PCM, no LERs dock to the PLM because it is expended and exchanged for a fresh one periodically. [9]

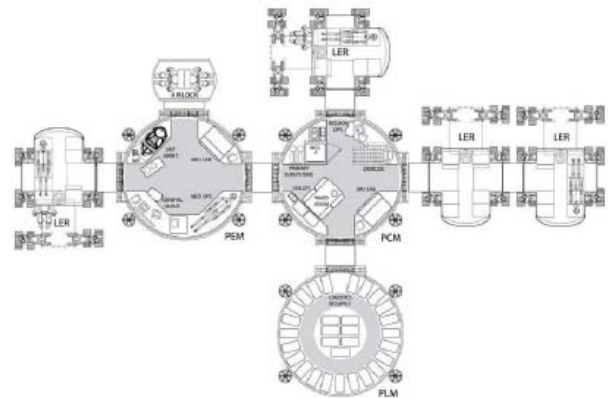


Figure 4. LSS 12.1 Lunar Outpost [9]

For purpose of this assessment, it is reasonable to assume that the four LERs would be replaced by four Multi-Mission Space Exploration Vehicles (MMSEVs), the in-space version of the LER. (The MMSEV is essentially a LER with the wheeled chassis replaced by a RCS propulsion sled.) That being said, there are some problems faced by the LSS 12.1 outpost if applied to a microgravity mission.

It is unclear if a transit spacecraft could have a balanced center of gravity with the LSS 12.1 outpost incorporated into the vehicle. Additionally, the number of docking ports would certainly result in a reduced structural

stability in the pressurized segment of the vehicle as compared with the planetary implementation.

LSS 12.1 features one LERs docked such that it is sandwiched between the PCM and another LER. In a planetary application it is a relatively trivial matter to deploy this “landlocked” LER by undocking the outboard one and allowing the inboard one to then undock and drive off. This will only consume electrical energy that can be readily recharged by docking the rovers with portable or fixed solar power stations. However, in a microgravity application, this consumes irreplaceable propellant, making it now an operation that will be limited by available resources.

The exercise equipment in the PCM is designed without consideration of any vibration isolation system (VIS). The ceiling height in the PCM may further make it impossible to incorporate a VIS and still provide appropriate headroom and reach envelopes for exercising crew members. For a planetary habitat this is acceptable as any loads induced by the exercise equipment are damped out by the ground. Without a VIS in a microgravity configuration, these loads will be transmitted to the spacecraft structure, which could cause damage if vibrations approach the natural frequencies of docking mechanisms, radiators, solar arrays, or other structural connections.

Thus, just as in the case of a microgravity habitat, one cannot simply take a habitat designed for use in a planetary environment and apply it to a microgravity mission. This has significant implications for extensibility and commonality. Given that it is not practical to stand up unique habitat development efforts for each environment, and that it is neither practical to design a habitat for microgravity and then use it in a planetary environment, nor to design a habitat for a planetary environment and then use it in microgravity, is it possible to design a habitat with consideration for both planetary and microgravity environments from the beginning, such that the resulting design is applicable in either mission scenario?

4 Proposed Skylab II Configuration

4.1 Project Origin

There has been interest from multiple stakeholders within NASA in exploring the idea of a habitat derived from a propellant tank of the Space Launch System, similar to the Skylab adaptation of the Saturn V S-IVB stage. These concepts have been informally dubbed the Skylab II concept. [2]

Most Skylab II data originates from the Advanced Concepts Office at NASA Marshall Space Flight Center. A Marshall configuration is shown in figure 5. This

configuration is designed exclusively for the microgravity environment. [2] However, the Habitability Design Center (HDC) at NASA Johnson Space Center has explored alternative configurations of the Skylab II.

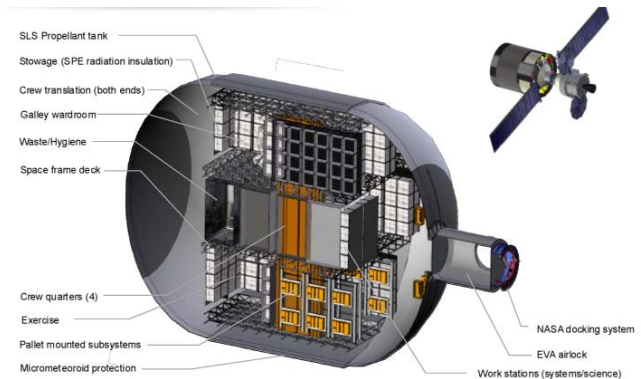


Figure 5. Skylab II Advanced Concepts Office Configuration

The HDC has explored a Skylab II configuration developed with the requirement that this habitat layout be a common design for all potential human exploration missions beyond LEO including lunar and Mars surface, Mars transit, deep space asteroids, and Cislunar space.

Like the other Skylab II concepts, the habitat uses an upper stage SLS hydrogen tank measuring 27 feet in diameter and 38 feet in length, with a volume of 495 m³. [1] The habitat is intended for use in 0G, 1/6G (Moon), 3/8G (Mars), and 1G (terrestrial – training) environments. This concept also assumes that logistics and trash are stowed in docked logistics modules and power, thermal, and propulsion are provided by separate, docked assets. [7]

4.2 Vehicle Configuration

The HDC configuration opted for a vertical orientation for the Skylab II concept, as opposed to the Marshall horizontal orientation. This allows for four decks as shown in figure 6. There are four radial docking ports, one dorsal docking port, and two vertical passageways on each deck.



Figure 6. HDC Vertical Orientation of Skylab II

4.3 Applicability of Habitat to Microgravity and Planetary Environments

4.3.1 Lower Dome

Due to the curvature of the lower dome of the Skylab II habitat, it is not suitable as a floor for walking in a planetary environment, but that does not cause it to become wasted volume. There is a large volume of space in the lower dome that is instead allocated to subsystems equipment and to vibration isolation systems for the exercise devices. As shown in figure 7, a crawl space in the lower dome sets up a racetrack configuration around the exercise VIS, allowing maintenance access to both the VIS and the vehicle subsystems.

The crawl space is large enough to access equipment and/or translate it through the crawl space to the vertical passageways, where it can be lifted to Deck 1 if necessary. Handholds provide translation aids for use in microgravity while wheeled trolleys and guide rails serve the same function in planetary environments.

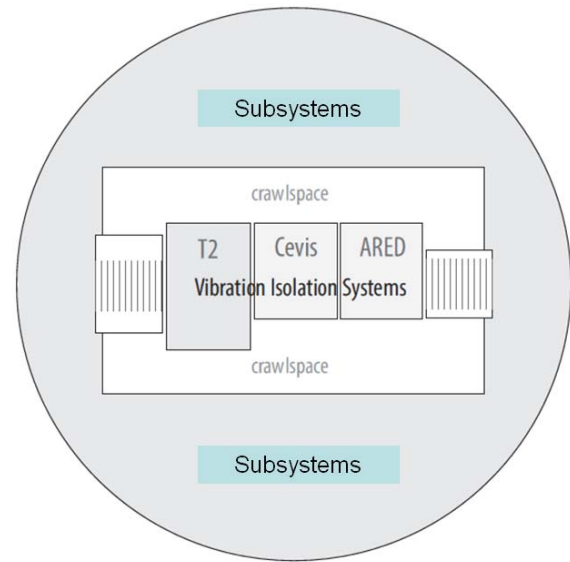


Figure 7. Lower Dome Floor Plan

4.3.2 Deck 1

Deck 1, whose floor plan is shown in figure 8, is the primary working deck of the habitat. Maintenance and fabrication workstations occupy a significant portion of the deck, providing capability to recover from any number of failure conditions. Crew exercise, life sciences, and suit storage are also located on this deck. In a microgravity configuration, the four docking ports provide access to an external airlock and some combination of a lunar/Mars lander, MMSEV (microgravity variant), and logistics module. In a planetary configuration, the lander would be replaced by either a second MMSEV (both surface variants) or second logistics module. Crew seats in the planetary configuration are exchanged for hand and foot restraints in the microgravity configuration.

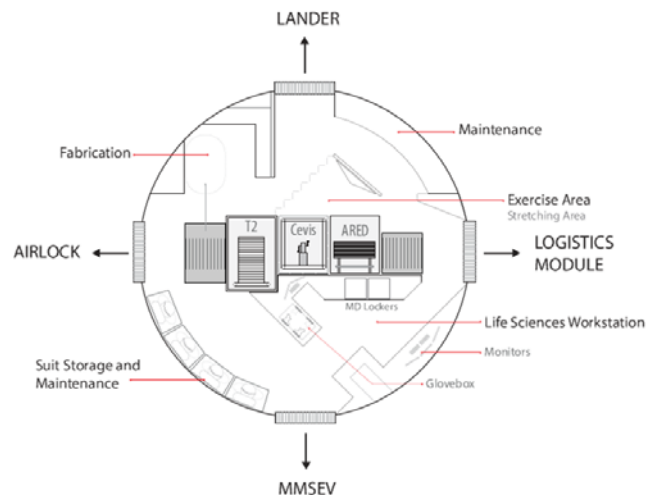


Figure 8. Deck 1 Floor Plan

4.3.3 Deck 2

Shown in figure 9, Deck 2 houses most of the private volumes in the HDC configuration of the Skylab II habitat. All of the facilities on this deck are designed to support privacy, including four crew quarters, a crew health/medical station, and a hygiene facility. Even the plant growth modules on the wall nearest the hygiene uses the walls of the hygiene facility to provide a partially isolated volume for a crew member who chooses to take a break in the vicinity of the greenery offered by the plants.

The crew quarters are specifically designed to function in both gravity environments with a horizontal crew bunk orientation. This results in a larger crew quarters than those used on Skylab or the International Space Station, which may also provide psychological benefits for deep space microgravity cruises. This added volume may enable crew members to conduct personal private projects (e.g. art, tinkering, etc.) that might not be possible in an ISS-style crew quarters.

The crew health and medical station is designed to rapidly receive crew members from any deck regardless of gravity environment. The vertical passageway adjacent to the station entrance is 40x60 inches in size, making passage easy in an incapacitated crew member scenario. In a planetary environment a hoist is used to facilitate transfer, while in microgravity a crew member can assist an injured shipmate with ease. Within the station an injured crew member is positioned on a medical table, elevated to an appropriate working height for a planetary environment. In microgravity the table can be repositioned in any desired orientation.

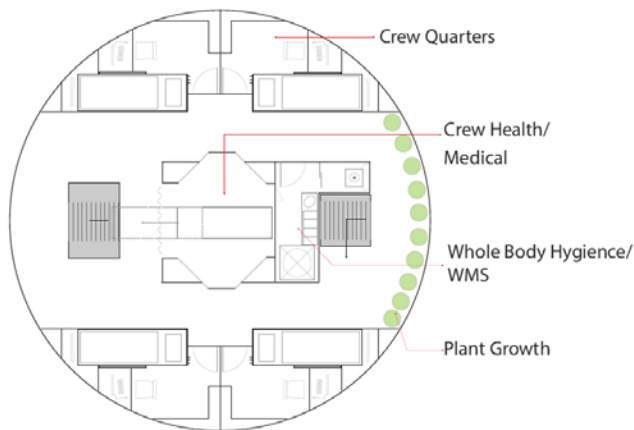


Figure 9. Deck 2 Floor Plan

4.3.4 Deck 3

Deck 3 is the operations and group social section of the Habitat. Because Deck 3 is partially in the barrel section and extends into the upper dome, it enjoys a ceiling heights

up to 11 feet, with the majority of the deck at least 6.5 feet in height. Figure 10 shows the basic floor plan.

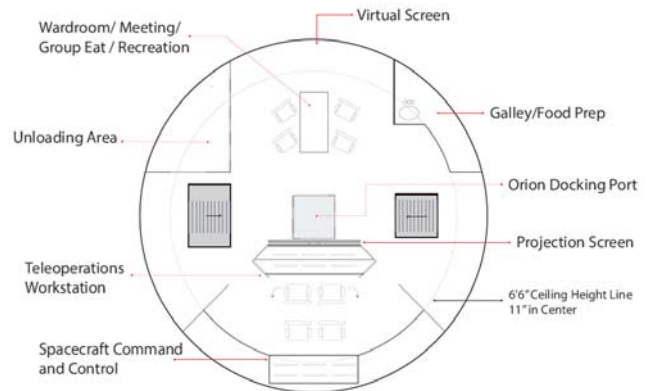


Figure 10. Deck 3 Floor Plan

The ceiling height works advantageously in both the planetary and microgravity applications of this habitat, providing a greater perception of volume. And in the lower gravities of the Moon, Mars, and space it also provides recreational opportunities that have not been enjoyed by astronaut crews since Skylab.

Partitions are used to provide a sense of separation between the operational and social sides of the deck as shown by the views in figures 11 and 12. Figure 12 particularly showcases the open volume that can be achieved on the social side when the wardroom table is stowed. In all gravity environments this area provides the crew with a flexible social space in which to unleash their creativity and invent new recreational diversions to better cope with the isolation of being separated from Earth in a long duration space mission.

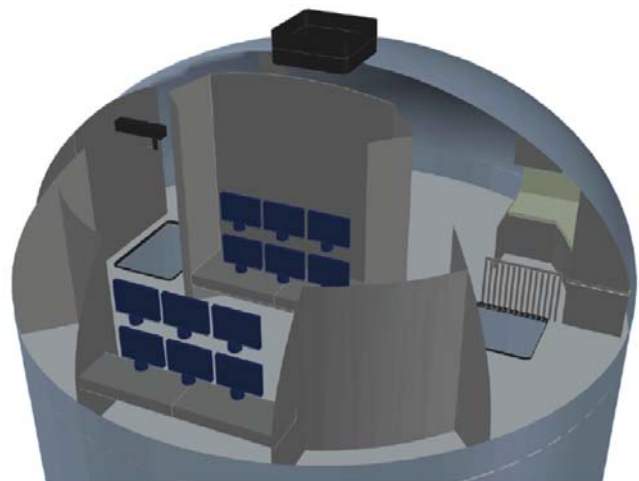


Figure 11. Operations Section of Deck 3

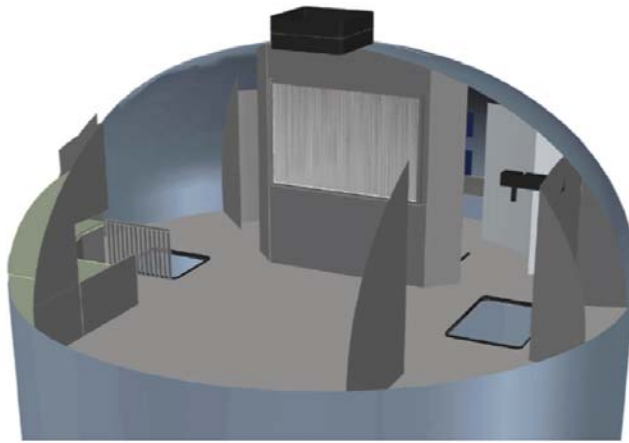


Figure 12. Social Section of Deck 3

5 Conclusions

5.1 Advantages in design phase and human performance compromises

Additional effort is required in the design phase to fully consider the impacts and implications of multiple environments. This may include attachment of pressurized and unpressurized modules in all environments, center of gravity, structural dynamics, local terrain, thermal considerations, interior design and architectural considerations due to gravity, crew tasks, and other considerations.

Throughout the habitat, vertical and horizontal surfaces must be designed to receive restraints or accommodations for both microgravity and planetary environments. With proper consideration early in the design phase, in some cases a common solution may provide functionality for both environments. Where this is not possible, sufficient attention must be given to design interchangeable solutions such that limited effort is required to outfit for microgravity versus planetary implementations.

These considerations may lead to some inefficiencies in packaging or efficiency of layout in one or both of the microgravity or planetary implementations. However, if a long duration habitat is successfully designed for operation in multiple gravitational environments, it has the potential to condense multiple project offices into a single project, with dramatic, potentially order of magnitude, cost and schedule savings for a human spaceflight program.

It is worth noting that the three habitats studied in this paper are all of relatively large volumes [1], [3], [9] driven primarily by the pressure vessels imposed on them. Designing the Skylab II habitat for multiple gravity environments did not impose any requirements to increase the size of the pressure vessel. Adding the multiple gravity

constraint upfront resulted in a design with significantly greater performance capability.

Acknowledgment

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